PROFILES OF REFRACTIVE INDEX AND HUMIDITY OVER THE WEST INDIES

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ABSTRACT

Profiles of refractive index over the West Indies based on the mean atmospheres of Gutnick and Jordan give no indication of the duct that is usually detected by radar at the trade-wind inversion. The discrepancy is attributed to the humidities that Gutnick assigns during "motorboating" of the radiosonde. If the presence of the duct is accepted at the trade-wind inversion and the necessary humidity profile inferred therefrom, compatible profiles of dew point and index of refraction are obtained.

1. INTRODUCTION

Operational experience with airborne and ground-based radars has provided ample evidence that an elevated duct is a semipermanent feature of the West Indies area. The duct coincides with the trade-wind inversion that separates a lower layer of warm, moist air from a still-warmer, exceedingly dry layer aloft. The primary cause of the duct is not the temperature inversion but the large drop in humidity[2] through the mixing zone separating the two air masses.

No useful climatology of the refractive index has been developed for this area although airborne refractometers have confirmed the presence of the duct [1], and a recent paper [5] deals briefly with the subject. A useful climatology of the trade-wind inversion in the Caribbean has been given by Gutnick [6], and Jordan [7] has provided mean atmospheres for the West Indies area. From these, an attempt was made to prepare a tentative climatology of the refractive index.

The method made use of the fact that the refractive index, N, measured in N units is related to the pressure, p, in millibars; the temperature, T, in °K.; and the vapor pressure, e, in millibars by the expression:

$$N=\frac{77.6p}{T}+\frac{373{,}256e}{T^2}. \tag{1}$$

The values of the constants in equation (1) are those recommended by Bean [3]. Since Gutnick provides data on the temperature and humidity structure at the inversion, and Jordan provides data on pressures and mean temperatures vs. height, it would appear a simple matter to compute mean profiles of refractive index associated with the trade-wind inversion from equation (1). When this was attempted, an unexpected difficulty arose. The lapse rate of refractive index at the inversion was substantially less than that needed to produce a duct.

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[2] *The Glossary of Meteorology* on p. 461 erroneously states that strong moisture inversions favor the formation of radio ducts.

It can be seen from equation (1) that the first term is proportional to the density and the second is proportional to the vapor pressure. The data provided by Gutnick and Jordan for the first term appear reliable, but Gutnick identifies a source of upward bias in the humidity data. The standard radiosonde is incapable of sensing humidity below certain critical values as a result of "motorboating." Whenever motorboating occurred, Gutnick entered the highest possible value for the humidity. Since motorboating is limited to the dry air at the top of the inversion and above, the practical effect of Gutnick's procedure is to underestimate the decrease in humidity across the inversion to the extent that normal propagation conditions are implied. It is clear that some procedure is needed that provides profiles of refractive index depicting the duct that is present. Such a procedure is outlined below.

2. RECOMMENDED PROCEDURE

From the inversion data given by Gutnick and the mean atmospheric data by Jordan, a temperature profile from the surface to 600 mb. may be constructed that conforms well to both sources (i.e., depicts the inversion correctly with minimum deviation from the mean temperatures). A question to be resolved is the lapse rate of dew point to be used with Gutnick's mean mixing ratio for the layer, 1,000 mb. to the base of the inversion. Figure 1 shows profiles of temperature and dew point for the midseasonal months of 1959 obtained by averaging published data [11] for Miami, San Juan, and Swan Island. The profile shapes are considered representative of average conditions over the West Indies. In general, the lapse rates of temperature and dew point are nearly the same in the lower layers. The tendency for the temperature and dew-point profiles to diverge between 900 and 850 mb. reflects the occasional lowering of the inversion below 4,000 ft. as reported by Gutnick. Accordingly, a lapse rate of dew point equal to that of the temperature was employed up to the base of the inversion. Equation (1) was then used with the vapor pressures

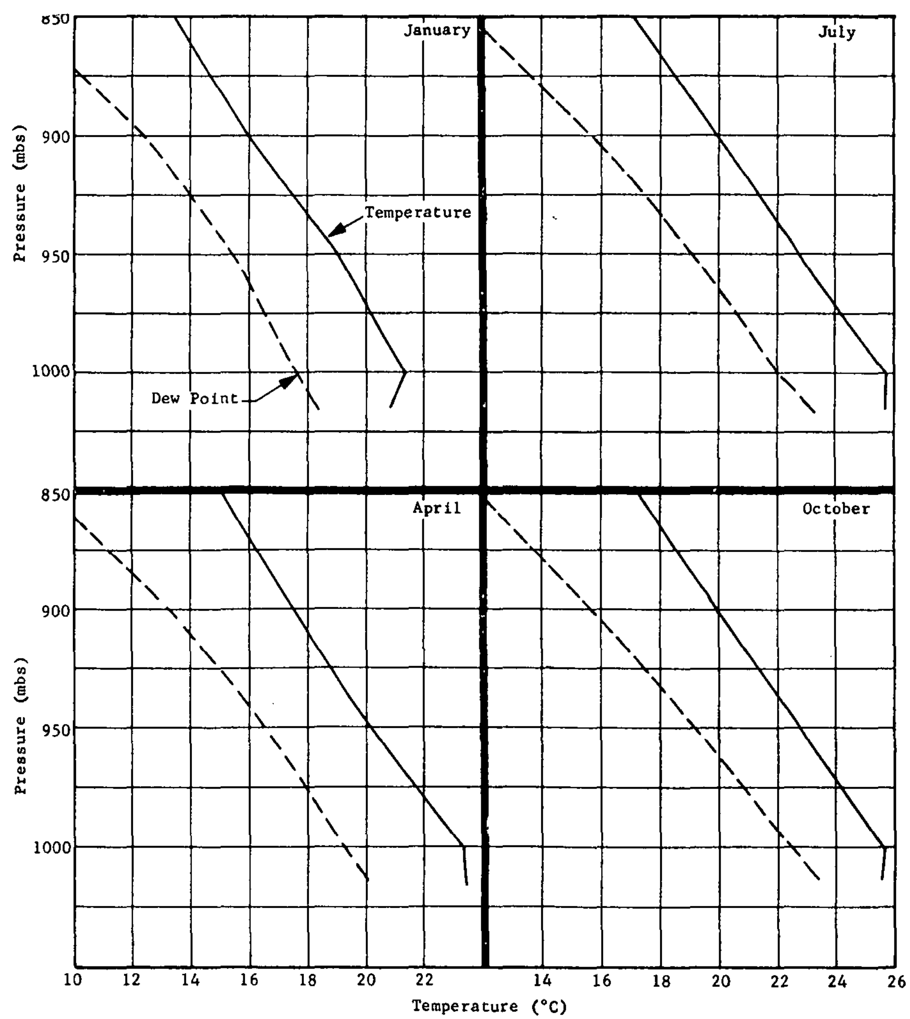

FIGURE 1.—Mean profiles of temperature and dew point over the West Indies, 1959, by months. (Mean of Miami, San Juan, Swan Island.)

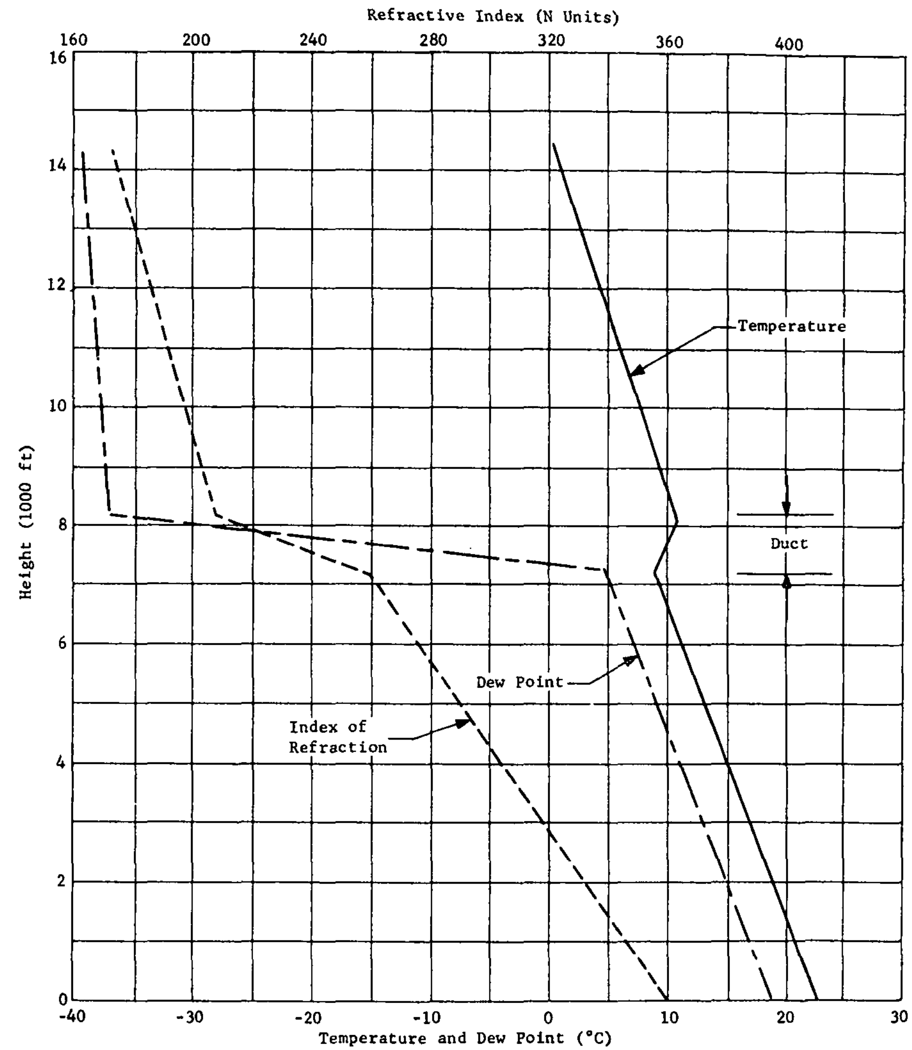

FIGURE 2.—Average profiles of temperature, dew point, and refractive index at the trade-wind inversion over the West Indies in January.

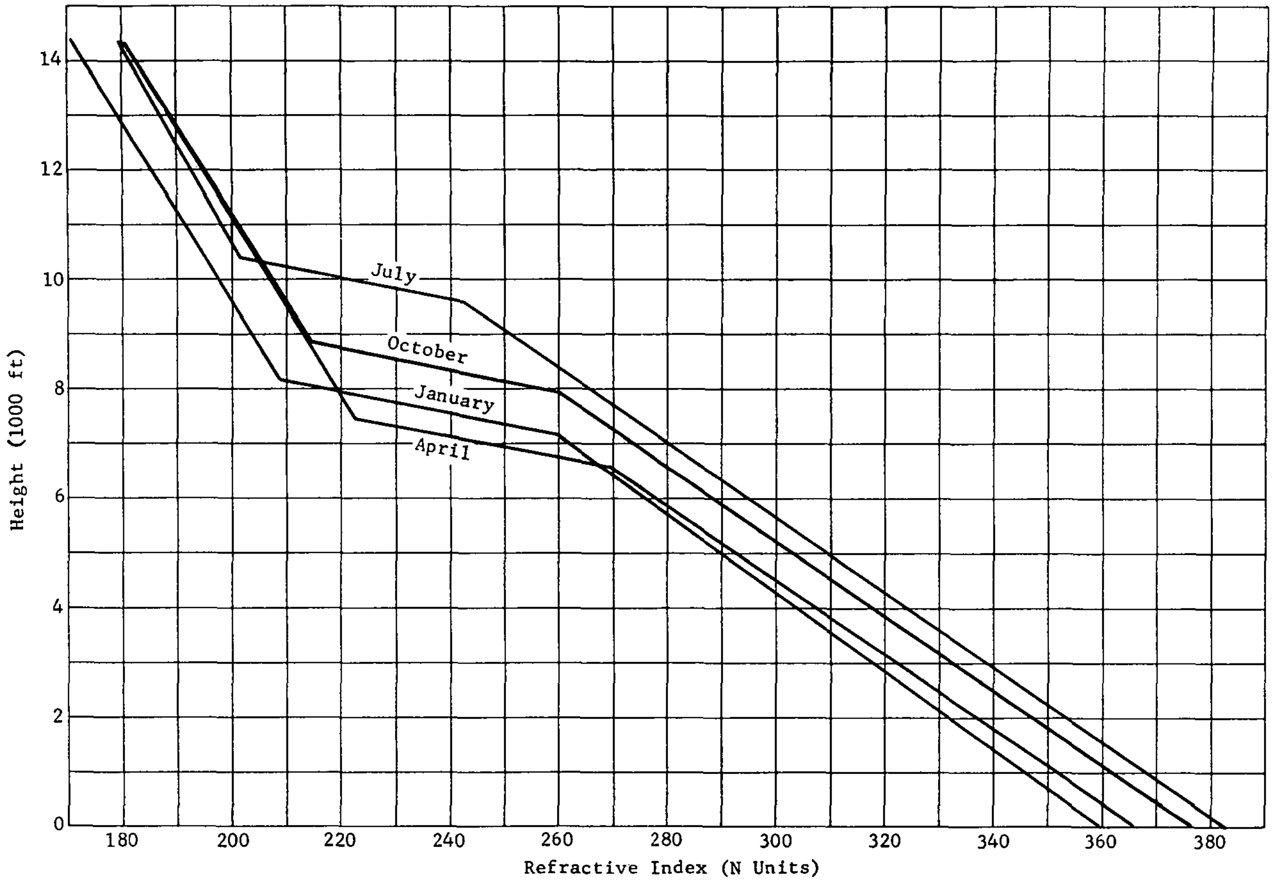

FIGURE 3.—Average refractive index profiles associated with the trade-wind inversion over the West Indies.

implied by the dew-point curve to evaluate the refractive index from the surface to the base of the inversion.

Ducting occurs when the lapse rate of refractive index exceeds 48 N/1,000 ft. According to McIntosh [8] the depth of duct required for anomalous propagation increases from 50 ft. for a wavelength of 3 cm. to about 600 ft. for a wavelength of 1 m. For a complete discussion of ducting and its dependence on radio frequency and depth of duct the reader is referred to the discussions by Booker [4] and Battan [2]. If one assumes a minimum lapse rate of 48 N/1,000 ft., the minimum increment of refractive index is easily computed for Gutnick's mean inversion thickness. This determines the maximum refractive index at the top of the inversion. The value for N is then used with equation (1) and the appropriate values of P and T to compute the vapor pressure, e, and, therefrom, the mixing ratio, w, using the expression:

$$w=\frac{0.622e}{p-e}. \tag{2}$$

The value of the vapor pressure is, of course, the maximum that can exist at the top of the duct. It is assumed that this same mixing ratio holds from the top of the inversion through to 600 mb., and equation (2) is used to compute vapor pressures, e, for the remaining data points. The computation of N using equation (1) now proceeds for the balance of the points, and a mean profile of refractive index is obtained.

To arrive at a mean for the area of interest, Gutnick's inversion data for Grand Bahama, Guantanamo Bay, and Swan Island were averaged and used with Jordan's mean values for the West Indies. An interesting byproduct of the procedure is a profile of the dew point, which is probably more realistic than the humidity profile given by Gutnick. The resultant profiles of temperature, dew point, and refractive index, at the inversion in January over the West Indies, are given in figure 2. Although the profiles generally portray average conditions, the increments of dew point and refractive index at the duct are the smallest that can produce a duct. It follows that the dew point at the top of the duct is the highest that it can be. The striking thing is the discontinuity in the dew point curve compared to the more subtle indications given by the curves of temperature and refractive index.

3. TENTATIVE RADIO CLIMATOLOGY OF THE WEST INDIES TRADE-WIND INVERSION

Figure 3 contains profiles of refractive index computed in the foregoing manner for the middle months of each of the seasons. Gutnick points out, however, that day-to-day variations in the height of the base and thickness of the inversion are considerable, and it is clear that no operational radar procedure can be based on these average curves.

4. REMARKS ON AIRBORNE DETECTION OF THE TRADE-WIND DUCT

The difficulties experienced by operators of airborne radars are described by Stansbury [10]. The operational mode is determined by height of the aircraft with respect to the duct. Consequently, the operator must know the height of the duct. Since the height and thickness of the duct vary considerably from day to day, the best procedure is to locate the duct on each mission by appropriate airborne meteorological measurements.

Figure 2 indicates the signatures of the duct that are provided by direct measurement of temperature, dew point, and refractive index. Since the most evident inflection occurs in the dew-point curve (about 40° C. in 1,000 ft.), it is suggested that aircraft equipped with a good dew-point sensor, such as that described by Mullen and Wolber [9], could pinpoint the boundaries of the duct with great accuracy.

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